THE CULTURE »

Books

A Noether genius

Emmy Noether ought to be as well-known as Albert Einstein. So why isn't she? And why are scientists indebted to her today?

by MARCUS CHOWN

Emmy Noether is responsible for an idea so important that it ranks alongside Charles Darwin's concept of evolution by natural selection as a central and unifying principle in science. It made possible the Standard Model—the high-point of 350 years of physics, which explains how the building blocks of matter, the quarks and leptons, are glued together by three fundamental forces—and it continues to provide a guiding light for those stumbling today in the darkness beyond the frontiers of current knowledge.

Noether's theorem reveals that the most powerful, overarching laws of physics are in fact mere reflections of a deep simplicity hidden beneath the skin of reality. As alluded to by the title of Lee Phillips's extremely well-written book, Noether discovered her theorem when she was in effect "Einstein's tutor".

In June 1915, Einstein—after an exhausting decade spent trying to find a description of gravity that was "covariant" (or the same for all observers)—accepted an invitation from David Hilbert, the greatest mathematician of his day, to lecture at the University of Göttingen. In the month of Einstein's stay, Hilbert provided both moral support and reassurance that he was on the right track. He also asked his protégé, Noether, to tutor Einstein on some of the maths he needed to complete his work, asking her, specifically, to investigate an apparent flaw in Einstein's embryonic theory.

The theory appeared to violate one of the cast-iron edicts of physics—that energy cannot be created or destroyed, also known as "the law of conservation of energy". It was while looking into this that Noether formulated her theorem—or, more accurately, four related theorems—which revealed a deep and utterly unexpected connection between conservation laws in general and "symmetries", things that remain unchanged during a transformation. Specifically, energy conservation turns out to be merely a trivial consequence of "time translational symmetry"—the fact that it makes no difference to the outcome of an experiment whether it is carried out today, next week or next year.

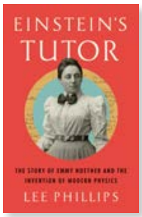
Noether realised, therefore, that energy is conserved only if it is possible to define a universal time that everyone agrees on. In Einstein's theory, this is not possible on the cosmic scale, since the rate of flow of time in any region depends on gravity, which in turn depends on the region's energy content. It did not mean that Einstein was wrong, Noether concluded, only that, in his theory, it made no sense to define the energy on the cosmic scale, since it was not an invariant quantity.

Noether's insight also revealed that other well-known conservation laws were nothing more than the flipside of the symmetries of space and time. "The law of conservation of momentum", for instance, is merely a reflection of "space-translation symmetry"—the fact it makes no difference to the outcome of an experiment whether it is done in London or New York or on Alpha Centauri. And "the law of conservation of angular momentum", responsible for an ice skater spinning faster as she pulls in her arms, is a consequence of "rotational symmetry"—the fact that it doesn't matter whether an experiment is aligned in a north-south direction or an east-west one, or any other orientation.

The immense power of Noether's theorem lies in its generality. It does not apply just to symmetries of space and time, but also to far more abstract, mathematical symmetries. Take, for instance, the electromagnetic field, the driver of all electric and magnetic phenomena. Here, as Phillips explains adroitly, the key symmetry involves voltage. Probably, we have all seen birds perched on high-voltage overhead cables. They can do this without harm because the voltage itself is unimportant. What causes injury is a voltage *difference* and in this case there is none—all parts of a bird's body are at the voltage of the power line. To experience a difference, the bird would somehow have to stay on the wire and simultaneously touch the ground, which is at 0 volts.

The fact that it makes no practical difference if the voltage is changed from zero to 50 volts to 50,000 volts is a symmetry. And, according to Noether's theorem, this implies a conservation law. The law in question is none other than "the conservation of electric charge".

The great edifice of the Standard Model was built from a recognition that the world around us is a consequence of a number of "quantum" symmetries. It took a scores of physicists scores of years to construct this model because of a pesky complication: in our low-energy world, we generally see only imperfect, or "broken", versions of the perfect symmetries that held at the super-high energies of the Big Bang. We can only fleetingly recreate these perfect symmetries in huge, expensive atom-smashers such as the Large Hydron Collider near Geneva.



Einstein's Tutor: The Story of Emmy Noether and the Invention of Modern Physics
by Lee Phillips
(PublicAffairs, £25)

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The mathematicians' mathematician: Emmy Noether helped Albert Einstein develop his grand theories

The Standard Model reveals that the universe, for some inexplicable reason, started off maximally symmetric and, like a fallen angel, has progressively lost its innocence. It's an unanswered question why god is so mad keen on symmetry.

An interesting aside, not raised by Phillips, is that the symmetries of the universe are exactly the symmetries that the universe would have if it contained nothing at all, if it were a void. The ultimate question of how something came from nothing may therefore be reduced to how nothing came from nothing—or at least how organised nothing came from nothing.

According to Phillips, Noether, by spelling out the conditions under which conservation laws apply, provided a precious "toolkit" with which physicists can constrain their ideas for potential theories beyond the Standard Model. It is in this sense that her theorem remains a guiding light for scientific explorers in the 21st century.

As for Noether herself, this woman responsible for shining so much light on our world, she is but a ghost haunting the pages of Phillips's book. We merely catch glimpses of her from the impressions of others. To be fair to Phillips, he does say that he has written a biography of an idea as much as of a person. And, of course, Noether's ethereality is the sad truth of her life. It accurately reflects the experience of a woman working in the male-dominated realm of academia in the early 20th century. For a long time, Noether was not paid, nor did she even have a formal academic post. Frequently, she saw men with abilities far inferior to hers promoted above her.

But part of the reason for Noether's obscurity, says Phillips, was her personality. She loved mathematics with such a passion that she didn't care for her physical appearance, nor for the ownership of her miraculous findings. Often, she happily handed them to others to claim for themselves. It was a generosity that was also apparent in other aspects of her life, where she was by all accounts eternally cheerful and high on life.

Her cheerfulness, however, was stretched to the limit by the Nazis. For not only was she a woman in a man's world, she was also a socialist sympathiser and a Jew, both of which were a potential death sentences under the Third Reich. "Forbidden by Hitler's regime to teach at all, she taught in secret, in her apartment," says Phillips. "Throughout it all, she enjoyed life, she raised the spirits and everyone around her, and, from joy, irony, and the delectation of absurdity, she laughed."

In 1933, just in the nick of time, she escaped to Bryn Mawr University in the US. And it is at Bryn Mawr that Noether's story connects with Phillips's own. As a physics student at Dartmouth College in New Hampshire, he had learned that symmetry underpins the great conservation laws of physics. But it was only later that he learned of a woman he had never heard mention of before. In the 1980s, Phillips had a girlfriend at Bryn Mawr, and the pair liked to walk in the faux cloister there, neither of them realising that beneath one of the paving stones lay Noether's ashes.

Noether's time in the US was the happiest of her life. However, she survived only two years before succumbing to a massive infection after the successful removal of a large ovarian cyst. She was just 53.

"In the judgment of the most competent living mathematicians," said Einstein, "Fräulein Noether was the most significant mathematical genius thus far produced since the higher education of women began." According to Frank Wilczek, a key contributor to the Standard Model, Noether's Theorem is "the single most profound result in all of physics". Phillips concludes that Noether "should be as well-known as Einstein".

Noether was born into an era where women were permitted so little in education. Not until 1923 was a woman appointed as a professor in Germany. Gradually, however, the door opened just a little, until Noether was able to force her way through. As Doris Lessing once said, "Any human anywhere will blossom in a hundred unexpected talents and capacities simply by being given the opportunity to do so." It was this law that Emmy Noether proved more than any other. ◆

Marcus Chown *is a science writer*